

Attachment A

TECHNICAL ANALYSIS

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SUMMARY AND PURPOSE

MobileVision fully supports the conclusion set forth by North American Teletrac and Location Technologies, Inc. ("Teletrac") in Impact of Co-Channel Interference on 900 MHz Wideband Pulse-Ranging AVM System Performance, Appendix 2 to Teletrac's Petition for Rulemaking, RM No. 8013, filed with the Commission on May 26, 1992 ("Teletrac's Appendix"). Teletrac's conclusion is that "a wideband AVM system. . . cannot operate in the presence of co-channel interference of the type that would be generated by additional wideband AVM systems or additional high powered CW carriers in the region."¹ While MobileVision supports Teletrac's conclusion and fully supports its analysis, with a few exceptions, MobileVision believes that the information contained in Teletrac's Appendix at points presents such a conservative view that the gravity of the problems caused by co-channel interference are underestimated. Specifically, Teletrac's analysis may underestimate the detrimental effects of co-channel interference because:

- 1) the declaration that four receive sites may be sufficient for adequate position determination is not realistic when at least five are necessary in an urban environment due to multipath bias;
- 2) interference between closely located co-channel vehicles which are not part of the same service

¹ Teletrac's Appendix, p. 31.

will negate the ability for either service to properly function;

- 3) some of the potential remedies cited in Teletrac's analysis for ambient interference are less practical than described in the analysis; and
- 4) calculating the attenuation of interfering signals through free space for sources of interference within one-half mile of a receive site is more typically done by the second power of distance rule than the fourth power of distance rule.

To place Teletrac's interference analysis and MobileVision's discussion of it in perspective, this Technical Analysis will first set forth the historical perspective of AVM technology and briefly describe how a standard AVM system operates. With this as background, this Technical Analysis will discuss those points of Teletrac's analysis which MobileVision believes understate the true gravity of co-channel interference. This analysis is not intended to replace or offer information contradicting Teletrac's analysis, rather the intention is to supplement the discussion where MobileVision believes Teletrac understates the severity of the co-channel interference problem.

HISTORICAL PERSPECTIVE

Developments Prior to 1974

In the late 1960's and early 1970's the Urban Mass Transportation Administration (UMTA) of the United States Department of Transportation was one of the prominent government agencies which recognized the crucial role that Automatic Vehicle Monitoring (AVM) would play in the future of transportation throughout America's cities. UMTA envisioned AVM to include Automatic Vehicle Location (AVL) and vehicle identification. These location and identification functions were to be performed through communications between vehicles engaged in the transport of persons, goods and services and central monitoring stations which were equipped to take immediate and long-term actions based on the information obtained from their vehicle constituency.

On two occasions in the early 1970's, UMTA solicited proposals from the industry at large to demonstrate AVM systems, and on each occasion UMTA awarded contracts to four corporations. Scores of companies bid for these opportunities. A senior member of the MobileVision team, a co-author of this Technical Analysis, was in charge of one of the teams awarded a contract. He was active in the early AVM investigations and demonstrations which, in part, led to the interim AVM rules adopted by the Federal Communications Commission ("FCC") in 1974. Carefully monitored by UMTA and MITRE Corporation, tests were run on each of these systems over a significant area within Philadelphia, Pennsylvania. In addition and at their own

expense, other major corporations, understanding the wide range of advantages associated with AVM, began testing systems in cities and suburban environments throughout the late 1960's and early 1970's.

Based on the large body of published data available by early 1973, it became clear that the use of FCC compliant radio band technologies for AVL, other than in those limited applications which employed fixed signposts, would not permit position determination accurate to within five hundred (500) feet. However, several things were learned during this period which would lead to the future development of effective radio location-based AVM systems.

First, it was discovered that the high degree of multipath bias encountered in both dense and in moderately dense urban environments probably rendered technologies other than wideband pulse-ranging impractical.² Tests conducted by the Hazeltine Corporation using pulse technology (lead edge tracking) in downtown Manhattan, demonstrated vehicle-to-single station dynamic multipath dispersion of a few hundred feet. The tests conducted in Philadelphia (using a standard 25 kHz UHF channel

² Multipath bias or ducting is a distortion of the position determination which occurs when the wideband pulse-ranging signal is not in a line-of-sight position with respect to the receive site. Because the pulse signal is reflected numerous times before it reaches the receive site its time of arrival at the site is later. Therefore, the mobile unit or vehicle is perceived to be farther from the receive site than it is. This phenomenon is very well described in Urban/Suburban Out-of-Sight Propagation Modeling by V. Erceg, S. Ghassemzadeh, M. Taylor, D. Li, And D. L. Shilling, presented in the June 1992 IEEE Communications magazine.

for phase tracking) demonstrated dispersions of about two thousand (2000) feet with virtually unrecognizable improvement attained using a few hundred kilohertz bandwidth, which was composed of several adjacent 25 kHz channels.

Second, the need for multilateration location solutions became obvious. Multilateration is the use of more stations than would be required in an open field when a line-of-sight path existed to each station from the vehicle. The need for multilateration is necessary because of multipath bias.

Third, those involved learned that background noise levels and interference within populated regions over the radio bands available prior to 1974 (for example, in excess of one microvolt within the UHF band) could render AVM impractical before the concept could become commercially viable.³ Interference and static multipath data were documented by the Sierra Research Corporation based on hundreds of thousands of independent signals within the UHF band which were recorded during the UMTA Philadelphia tests. A similar body of such tests now exists throughout the literature for virtually all radio bands under consideration for AVL usage.

Fundamental Requirements of AVM Systems

During the hearings conducted by the FCC prior to the release of the 1974 interim rules, two requirements were apparent if AVM was to become commercially viable. In order for

³ See, U.S. Department of Transportation, Urban Mass Transportation Administration Automatic Vehicle Monitoring System Final Report, Report No. TR-0932, Contract No. DOT-UT-10024, dated February 1973.

investments in AVM technology to become viable and to develop AVM systems with sufficient accuracy so they would benefit the public and efficiently utilize spectrum, a wideband of spectrum would need to be set aside for AVM. Large scale capital investment also would be necessary from those providing AVM service.

First, no spectrum had been allocated free from interference for commercial development and use of wideband pulse-ranging technology. As had been learned through the previous tests and studies, this spectrum would have to be relatively free from harmful interference if pulse-ranging technology was to be used for location purposes.⁴

Second, in addition to the costs associated with designing, manufacturing, installing and maintaining a considerable vehicular equipment inventory, it was clear that a high density of fixed radio sites and a well-staffed sophisticated central station with all its attendant communications interfaces was required. Thus, it was realized that a large capital expenditure would be necessary for entry into the AVM field. Since any one AVM service provider would utilize the entire set-aside band at any given instant in a given area, it was further recognized that it would be impractical for more than a single provider to operate within that band. As long as spectrum utilization was significant and a meaningful user base was being well-serviced by a provider, it was generally

⁴ At that time, wide scale use of a technology later to be known as spread spectrum was already becoming the United States military's primary method for pulse ranging.

understood that the delivery of AVM service within an area and within the assigned band, implied exclusive usage of that band. In fact, in order to permit choice between two AVM providers within a given service area, the FCC established two such 8 MHz bands.

At the time the FCC released the interim AVM rules in 1974, it was clear that the implementation of two extensive AVM systems, each of which fully occupies 8 MHz of reserved spectrum, would be authorized to organizations which effectively utilized this spectrum. The term "extensive" is used here to reflect the need for a considerably high density of fixed sites than would be necessary with AVL service and for the provision of a broad enough range of services to attract a sufficient customer base.

Technological Developments Since 1974

Both the commercial viability of AVM systems and their capacity have dramatically improved since 1974 and the release of the interim rules. The single most important factor contributing to the commercial viability and capacity of AVM systems was the advent of very large scale integration ("VLSI"). VLSI has made possible (1) the miniaturization of the mobile units, (2) the miniaturization and affordability of microcomputer equipment, and (3) the increased processing capacity of microcomputers.

VLSI has reduced the size and power consumption requirements of mobile units. Today, mobile units assembled with off-the-shelf parts can be produced at a size and weight of

5" by 7" by 2" and approximately two pounds, respectively. With further integration and customized design, they can be produced at an even smaller size. As a result, mobile units can be installed in vehicles in a more economically feasible manner. Moreover, miniaturized mobile units can be mounted in or placed on nonvehicular objects, animate or inanimate, or carried by persons. Therefore, miniaturization of mobile units has allowed AVM operators to expand their services beyond vehicular services.

VLSI has also reduced drastically the size and the cost of microcomputer equipment. Microcomputers are utilized at the fixed sites and the control center to process the signals and data received and to perform position determinations. Since 1974, this equipment has integrated functions into increasingly smaller units. Moreover, the price of the equipment has fallen tremendously. As a result, constructing multi-site AVM systems, while still providing affordable service to customers, has become a commercial reality.

In addition to miniaturizing both the mobile units and the control equipment, VLSI has improved AVM services by permitting the control equipment to determine the relative time of arrival⁵ of a ranging pulse with far greater accuracy. When using a time of arrival location methodology, measuring the precise time at which the wideband pulse-ranging signal transmitted by the mobile unit arrives at the receive site is critical. Today's

⁵ The time differences of arrival are computed at the control center.

systems can measure the arrival of a wideband pulse down to 20 nanoseconds, which, given the speed of a radio wave, is the equivalent of approximately 20 feet.

Thus, VLSI has (1) permitted the monitoring and location of persons and objects other than vehicles, (2) made AVM systems commercially viable by reducing the size and cost of the microcomputer equipment used to control and operate the system and (3) made AVM systems more dependable by increasing the precision and accuracy of the control calculations.

INTERFERENCE ANALYSIS

System Description

In order to understand the detrimental effect interference has on AVM systems, one must have at least a basic understanding of the signaling sequence generated by an AVM system. Figure 1 below shows a schematic of an AVM system and three of its essential components, the receive fixed sites ("RFS"), the transmit/receive fixed sites ("TFS") and the control center.

The control center processes the data it receives via landline connections from the TFSs and performs the position determination calculation. When a mobile unit transmits a narrowband signal indicating, for example, that the vehicle has been stolen or is in distress, that signal is received by the TFS. The TFS notifies the control center and instructs the mobile unit how to transmit its wideband pulse-ranging signal. The communication from the TFS to the mobile unit uses the forward link (narrowband) and is absolutely critical to the

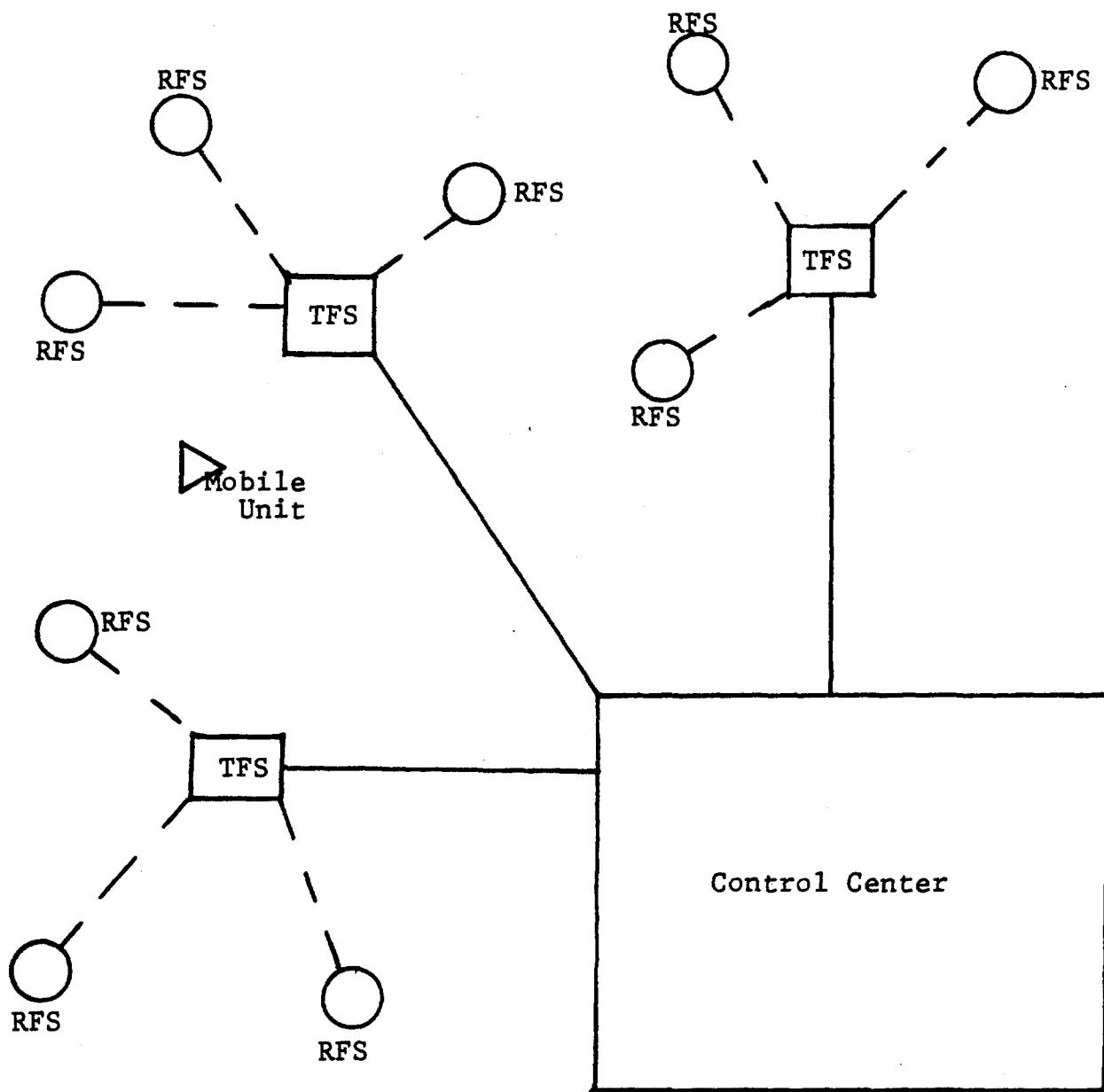


FIGURE 1

location process because without it the wideband pulse-ranging signal used for determining the mobile unit's location will not be appropriately transmitted. The mobile unit then transmits its wideband signal to the RFSSs and TFSSs, which then relay the time of arrival data via the TFSSs to the control center for processing.

Sources and Effects of Interference

Any co-frequency device or signal within the 8 MHz bandwidth set aside for AVM operations will interfere with AVM operations, whether the interference is narrowband or wideband. Specifically, the sources of interference experienced by AVM systems are industrial, scientific and medical equipment, amateur radio operators, wireless local area networks ("LANs") and tag readers, e.g., toll booth operators and the anti-shoplifting clothing tags. Generally, the LANs and clothing tag operators ("Part 15 Users") use spread spectrum technology, while the toll booth and amateur radio operators may appear as high power narrowband interference. Presently, no actual interference is experienced from co-channel AVM operators because no market has experienced the simultaneous operation of two co-channel AVM service providers.

Other co-channel AVM operators such as those described present a serious problem because the interference that they create is very difficult, if not impossible, to eliminate because the operator suffering interference cannot control the interfering signal. AVM operations can cause self-induced interference as well. However, MobileVision can control this

self-induced interference using a combination of techniques designed to maximize system capacity. This is achieved through a complex combination of techniques that control the allocated spectrum. Depending upon the services utilized, ranging accuracy is achieved by using the highest chipping rate consistent with spectral containment. CDMA, TDMA, and FDMA techniques are used to further control the allocated spectrum so that the required narrowband transmissions do not interfere with spread spectrum transmission (and vice versa) and are spectrally contained. Such control is not possible if independent co-channel operators are present in the same 8 MHz band.

Whatever the source of interference, its strength and the distance between the source of interference and the receive sites are critical to the accurate and reliable operation of AVM systems. MobileVision strongly supports and concurs, with the exception of a few points discussed below, with the interference analysis submitted by Teletrac in support of its Petition for Rulemaking. Teletrac quite thoroughly demonstrated that AVM systems cannot withstand the harmful interference which will be generated by another co-channel AVM system in the same 8 MHz band. Teletrac used two approaches by which to make this demonstration. First, it showed that the reliability of the position determination and, thus, system accuracy fall off over a range of increasingly more powerful sources of interference. Second, Teletrac demonstrated how the presence of one source of co-channel interference within and on the fringe of an AVM system service area degrades the coverage of the system.

Teletrac, however, did not fully demonstrate the manner in which interference disrupts AVM operations.

Interference to the narrowband transmissions of an AVM system can essentially render the system inoperable. For instance, if, at the time a vehicular mobile unit is transmitting on the narrowband channel to the TFS to indicate that the vehicle is in distress, a more powerful signal from an amateur radio operator drowns out the mobile unit's signal, the TFS would not detect the distress signal. To avoid nondetection of the mobile unit's signal, the system would have to allocate more time resources. However, this considerably reduces the capacity of the system by reducing available resources, and thus, disrupts the system's multiplexing. Such a remedial action would considerably increase the cost to the end-user.

Interference to the wideband pulse-ranging signals has its own complexities. While interference to the narrowband communications threatens an AVM system by destroying vital set-up and command signals, interference to the wideband pulse-ranging signals severely reduces the accuracy with which an AVM system locates mobile units.⁶

As described by Teletrac, AVM systems locate the mobile units by means of multilateration. In other words, the wideband signals transmitted by a mobile unit are received at multiple

⁶ By way of example, MobileVision engineers recently were measuring the sensitivity of a receive site when they received the signals of mobile amateur radio operators. The interfering signals were 16 dB greater than MobileVision's spread spectrum signal. Unfortunately, no call signs were given by which to identify the operators.

RFSSs and TFSSs, and the time difference between each time of arrival at the receive sites determines the location of the unit. In theory, the intersection of the lines of position "drawn" around each receive site is a single point in space.⁷ To a point, the greater number of sites receiving the wideband signal, and therefore, the greater number of lines of position used in determining the location, the greater the accuracy of the determination.⁸ However, noise and interference corrupt the wideband signal so that its time of arrival is distorted and the intersection of the lines of position becomes a region and not a point.⁹ If the wideband signal is sufficiently corrupted by co-channel interference, the calculated time of arrival is not useable for purposes of locating the unit and the data is discarded. Reducing the number of RFSSs or TFSSs involved in the determination of a unit's location reduces the accuracy of that determination.¹⁰ Thus, interference to the wideband pulse-ranging signal does not interrupt the signal, but it can

⁷ Teletrac's Appendix, pp. 6-8.

⁸ A distinction should be made between spread spectrum technology used for location purposes and that used for communications purposes. When spread spectrum technology is used for communications purposes, receiving the wideband signal at more than one site is not critical because the content of the signal is the important aspect of the communication. When spread spectrum technology is used for location purposes, however, the important aspect of the communication is not the content of the signal but reception of the signal and the reception of that signal at a sufficient number of locations to determine the origin of the signal.

⁹ Teletrac's Appendix, pp. 6-8.

¹⁰ Id.

corrupt it sufficiently to make determining the signal's time of arrival impossible.

Clarifications of Teletrac's Analysis

While MobileVision fully supports Teletrac's conclusion that co-channel separation is required to avoid interference and supports generally Teletrac's technical analysis in support of its conclusion, there are a few points in Teletrac's analysis where MobileVision believes Teletrac was too conservative, and thus, underestimates the detrimental effect of co-channel interference.

First, MobileVision believes that, with the level of interference that exists in the areas where AVM systems operate, a minimum of five receive sites must independently receive the wideband pulse-ranging signal to make an accurate calculation of a unit's location. Use of less than five receiving sites in an urban environment can cause severe degradation of accuracy.

MobileVision's interpretation of Teletrac's intent is that Teletrac does not actually support the possibly misleading inference that the minimum number of receive sites necessary for sufficient accuracy is four.¹¹ Teletrac did not specifically account for multipath bias in conjunction with Geometric Dilution of Precision ("GDOP").¹² Street profiles play a

¹¹ Teletrac's Appendix, p. 9.

¹² GDOP is the distortion of the lines of position as the mobile unit becomes more distant from the center of the receive sites. As the mobile unit moves farther from the center of the receive sites the lines of position become parallel and their "points" of intersection widen. Teletrac's Appendix, pp. 12-13.

significant role in the electromagnetic path of travel within urban and suburban environments.¹³ Errors of hundreds of feet over a single path between a mobile unit and a receive site can be encountered in a multipath environment. When such a case exists, if only four receive sites are used in the position determination, even under reasonably good GDOP conditions, mobile unit positions can be determined which approach a city's block length in error. Under bad GDOP conditions, situations where more than a thousand feet of error occur are not uncommon when an insufficient number of sites are used to determine a vehicle's position.

When at least five receive sites are utilized in a position determination, the negative impact of multipath bias is greatly alleviated. After more than eight to ten receive sites are utilized the paths of travel become less independent and there is little or no gain in accuracy from the use of additional sites in the position determination. In an example cited by Teletrac, their "base case" (a case where there was no external interference) normally utilized an average count of 7.1 receive sites per position determination. Thus, MobileVision concludes that Teletrac relies on five or more receive sites to achieve the required accuracy.

¹³ The geometry associated with the electromagnetic path of travel between out-of-sight points is demonstrated both graphically and mathematically on page 58 of Urban/Suburban Out-of-Sight Propagation Modeling, IEEE Communications Magazine, June 1992.

Second, Teletrac does not account for vehicle interference from co-channel AVM systems in the same geographic area. Other AVM services operating on the same 8 MHz band in the same area would create unacceptable interference to both the wideband pulse and narrowband communications. Co-channel AVM system operators would corrupt the wideband pulse signals and confuse the control functions of the other AVM system. For example, if two mobile units, one from each AVM system, were transmitting either narrowband or wideband signals while in the same proximate area neither system would be able to differentiate between the vehicles.

Vehicle interference is not presently a problem for operating AVM systems because thus far no two AVM systems are operating on the same 8 MHz band in any particular geographic area. However, because presently two AVM systems can be licensed in the same 8 MHz band in the same geographic area, the possibility exists, if both licensees build-out and commence operations, that neither will be able to operate their systems due to interference from the other.

Third, Teletrac thoroughly demonstrates both from a 95% reliability and from a coverage point of view, how detrimental the effect of one interfering source is on the operation of an AVM system. However, it does not account for the "ambient" noise and interference in addition to the single sources of interference. The most common source of ambient noise is Part 15 Users. While the ambient noise itself does not render an AVM system inoperable nor considerably distort its accuracy, ambient

noise does raise the interference level seen by receive sites so that the operation of a co-channel AVM operator would have a greater detrimental effect on the other AVM system than indicated in Teletrac's Appendix.

Fourth, when estimating the strength of interfering signals in its analysis, Teletrac relies on the r^4 attenuation law to determine the extent to which any interference will attenuate by the time it reaches a receive site. However, for distances up to and often exceeding one-half mile, it has been established that attenuation tends to follow a second power of distance (r^2) rule. Under line-of-sight conditions (excluding multipath bias), this second power of distance condition holds true as long as the product of twice the receiver antenna height and twice the transmitter height exceeds the product of the wavelength and the distance between the antennas. At 900 MHz this means that the square law susceptibility to interference may exist until one-quarter the distance between the interferer and site exceeds the product of the interfering and receiver antenna heights. MobileVision's measurements confirm the validity of using the second power of distance rule within one-half mile under line-of-sight circumstances.

MobileVision emphasizes the impracticality of the remedies for overcoming interference which were also dismissed by Teletrac.¹⁴ The only practical method mentioned for effectively increasing power was lengthening the spread spectrum transmission duration. In a noisy environment, indeed a four

¹⁴ Teletrac's Appendix, pp. 17-19.

times longer pulse increases measurement accuracy between a site and a vehicle by a factor of two. During an extensive study conducted in the UHF band in Philadelphia, it was demonstrated that in noise-limited suburban areas the effect of pulse width was found to be significant. The same study also demonstrated that in a high multipath occurrence, interference-limited environment, increasing the pulse duration provided no change in the accuracy of the time of arrival measurement.¹⁵

CONCLUSION

Co-channel interference within the same 8 MHz band is not tolerable for accurate and dependable AVM system performance. Teletrac's Appendix makes this clear and MobileVision supports that conclusion. However, co-channel interference is even more detrimental to AVM operations if one considers such factors as multipath bias, ambient interference, less attenuation of nearby sources of interference under the second power of distance rule and vehicular interference from another AVM system operating on the same bandwidth. These factors should be considered to supplement Teletrac's analysis in order to understand the full detrimental effects of co-channel interference

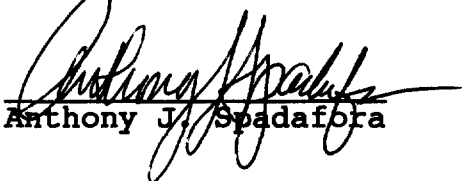
¹⁵ The information presented in this study is based on the recorded time of arrival measurements associated with over one hundred and fifty thousand (150,000) position determinations.

JOINT DECLARATION OF
BASIL E. POTTER AND ANTHONY J. SPADAFORA

I, Basil E. Potter, am Vice President for Mobile Electronic Tracking Systems ("METS"). I, Anthony J. Spadafora, am Vice President - Technology for METS. We have examined the petition for rulemaking filed by North American Teletrac and Location Technologies, Inc., including Appendix 2 thereto, In the Matter of Amendment of Section 90.239 of the Commission's Rules to Adopt Permanent Regulations for Automatic Vehicle Monitoring Systems (RM No. 8013). We have prepared the foregoing technical analysis, and we declare under penalty of perjury that the foregoing technical analysis, to the best of our knowledge, is true and correct.



Basil E. Potter



Anthony J. Spadafora

Dated: July 22, 1992